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**7th Edition**

**An international reference work in twenty volumes including an index**

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1234567890 DOW/DOW 998765432

Library of Congress Cataloging in Publication data

McGraw-Hill encyclopedia of science & technology : an international reference  
work in twenty volumes including index. — 7th ed.  
p. cm.

Includes bibliographical references and index.

ISBN 0-07-909206-3

I. Science—Encyclopedias. 2. Technology—Encyclopedias.

I. Title: McGraw-Hill encyclopedia of science and technology.

II. Title: Encyclopedia of science & technology.

III. Title: Encyclopedia of science and technology.

Q121.M3 1992 503—dc20

91-36349

CIP

ISBN 0-07-909206-3 (SET)

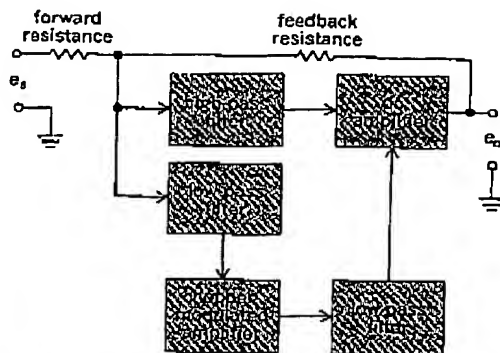


Fig. 4. Chopper-stabilized amplifier.

per-modulated amplifier, because the high-pass and low-pass filters direct the frequency components of the input signal into the separate amplifiers. Thus, for dc and very low frequency signals the open-loop gain is equal to the gain of the chopper amplifier times the gain of the dc amplifier, while for higher-frequency signals the gain is that of the dc amplifier alone. However, if the gains are large, then when the feedback network is connected, the gain is equal, to a good approximation, to the feedback impedance divided by the impedance in the forward path. The gain is, therefore, essentially independent of the open-loop gain, and the dc amplifier drift has been significantly reduced.

Chopper-stabilized amplifiers find wide application in analog computers, where they are used in integrating and summing amplifiers. In many problems solved on analog computers the time scale is reduced. This imposes strict requirements on the freedom from drift of the dc amplifiers. These requirements are met with amplifiers where a typical value for the dc amplifier gain is 100,000 and a typical value for the gain of the chopper-modulated amplifier is 1000.

Christos C. Halkias

**Bibliography.** J. J. Brophy, *Basic Electronics for Scientists*, 4th ed., 1983; C. H. Evans, *Electronic Amplifiers: Theory, Design and Use*, 1979; D. G. Fink, *Electronics Engineer's Handbook*, 2d ed., 1982; C. A. Holt, *Electronic Circuits: Digital and Analog*, 1978; D. L. Schilling and C. Belove, *Electronic Circuits: Discrete and Integrated*, 1979.

### Direct current

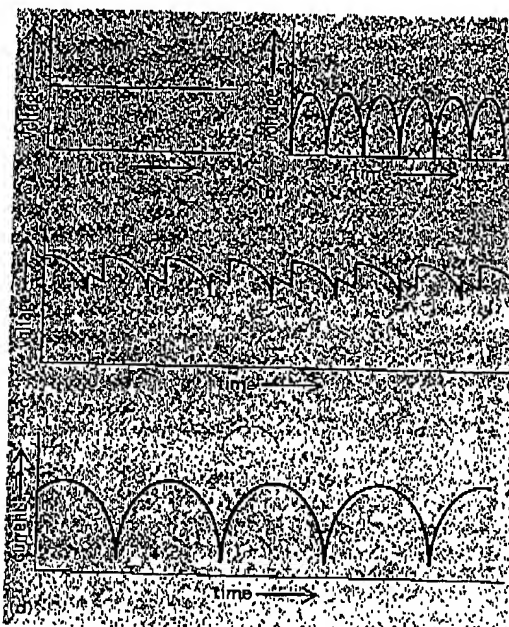
Electric current which flows in one direction only through a circuit or equipment. The associated direct voltages, in contrast to alternating voltages, are of unchanging polarity. Direct current corresponds to a net displacement of electric charge in one unvarying direction around the closed loop or loops of an electric circuit. Direct currents and voltages may be of constant magnitude or may vary with time.

Generators and rotating generators produce direct currents of nominally constant magnitude (illus. a). Voltages of time-varying magnitude are produced by rectifiers, which convert alternating voltage into direct voltage (illus. b and c). *SEE BATTERY; RECTIFIER.*

Direct current is used extensively to power adjust-

able-speed motor drives in industry and in transportation (illus. d). Very large amounts of power are used in electrochemical processes for the refining and plating of metals and for the production of numerous basic chemicals. *SEE ELECTROCHEMICAL PROCESS; ELECTROPLATING OF METALS.*

Direct current ordinarily is not widely distributed for general use by electric utility customers. Instead, direct-current (dc) power is obtained at the site where it is needed by the rectification of commercially available alternating current (ac) power to dc power. Solid-state rectifiers ordinarily are employed to supply dc equipment from ac supply lines. Rectifier dc sup-



Typical direct currents and voltages. (a) Output from a battery; (b) full-wave rectified voltage; (c) output of the rectifier station of a high-voltage dc transmission link (after E. W. Kimbark, *Direct Current Transmission*, vol. 1, Wiley-Interscience, 1971); (d) Current in a rectifier-supplied dc motor (after A. E. Fitzgerald, C. Kingsley, and A. Kusko, *Electric Machinery*, 3d ed., McGraw-Hill, 1971).

plies range from tiny devices in household electronic equipment to high-voltage dc transmission links of at least hundreds of megawatts capacity. *SEE ELECTRIC POWER SYSTEMS; SEMICONDUCTOR RECTIFIER.*

Many high-voltage dc transmission systems have been constructed throughout the world. Very large amounts of power, generated as ac and ultimately used as ac, are transmitted as dc power. Rectifiers supply the sending end of the dc link; inverters then supply the receiving-end ac power system from the link. High-voltage dc transmission often is more economical than ac transmission when extremely long distances are involved. *SEE ALTERNATING CURRENT; ELECTRIC CURRENT; TRANSMISSION LINES.*

D. D. Robb

### Direct-current circuit theory

An analysis of relationships within a dc circuit. Any combination of direct-current (dc) voltage or current sources, such as generators and batteries, in conjunction with transmission lines, resistors, inductors, capacitors, and power converters such as motors, is

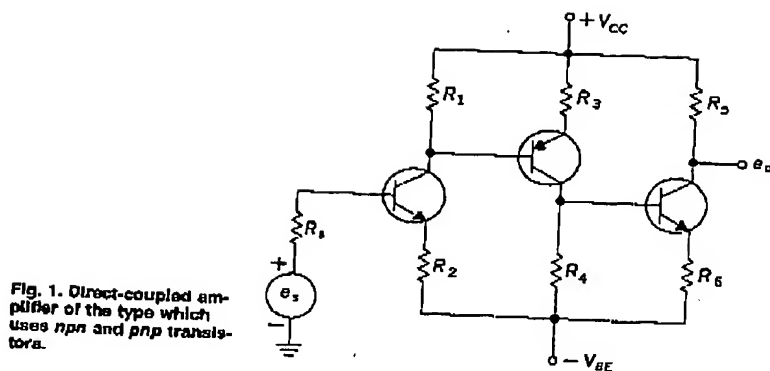


Fig. 1. Direct-coupled amplifier of the type which uses npn and pnp transistors.

amplify alternating-current (ac) signals. *SEE AMPLIFIER.*

Some type of coupling circuit must be used between successive amplifier stages to prevent the relatively large supply voltage of one stage from appearing at the input of the following stage. These circuits must pass dc signals with the least possible amount of attenuation.

Transistor direct-coupled amplifiers have a number of advantages and disadvantages relative to vacuum-tube amplifiers. Interstage direct coupling is much easier with transistors because of the availability of both pnp and npn transistors and Zener diodes. The circuit of Fig. 1 is a direct-coupled amplifier. The main disadvantage of this amplifier is the temperature dependence of the transistor parameters, specifically the current gain  $h_{FE}$ , the base-to-emitter voltage  $V_{BE}$ , and the leakage current  $I_{CBO}$ . Very often a Zener diode is used to couple between stages, and in that case it is not necessary to use both pnp and npn transistors. The Zener diode has a range of values of current through the diode for which the voltage across it is nearly constant. In effect, the Zener diode acts like a battery.

**Differential dc amplifier.** It is generally recognized that the differential amplifier is the most stable dc amplifier circuit available. This is true because in this circuit the performance depends on the difference of the device parameters, and transistors can be manufactured using the planar epitaxial technique with very close matching of their parameters. Figure 2 shows a

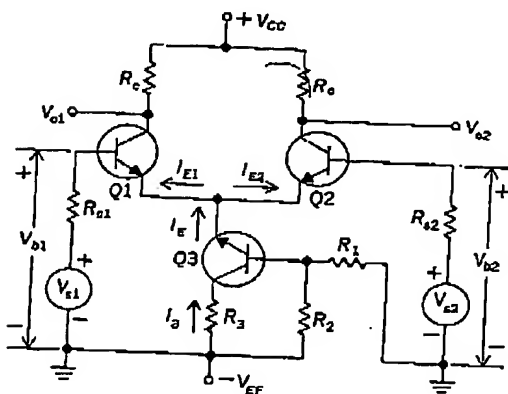


Fig. 2. Differential dc amplifier with constant-current stage in the emitter circuit.

differential amplifier with a constant current in the emitter circuit.

**Carrier amplifier.** A method of amplifying slowly varying signals by means of ac is to modulate a carrier signal by the signal to be amplified, amplifying the modulated signal, and demodulating at the output. (In some applications, such as instrument servomechanisms, output in the form of a modulated carrier is required and no demodulation is necessary.) One arrangement is illustrated in diagram form in Fig. 3.

An analysis of an actual circuit would show that in order to have an output  $e_o$  free from harmonics introduced by the modulation, the output low-pass filter cutoff frequency must be small compared to the modulation frequency. This limits the bandwidth of the input signal  $e_s$  to a small fraction of the bandwidth of the

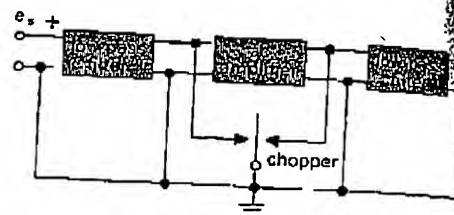


Fig. 3. Chopper amplifier.

signals which can be amplified by the types previously discussed. This is a disadvantage in most cases, but there are cases, such as the output voltage from a thermocouple, where the required bandwidth is small. Various types of choppers (bipolar transistors, field effect transistors, and electromechanical devices) are used as modulators. An additional disadvantage is that the chopper must be carefully designed to reduce to a minimum the hum and noise which can be introduced by an electromechanical element and the offset voltage and leakage current of a transistor. However, this amplifier provides stable amplification of the input signal, and it is used in many industrial recording instruments. *SEE MODULATION; VIBRATOR; VOLTAGE AMPLIFIER.*

**Chopper-stabilized amplifiers.** A chopper-stabilized amplifier is composed of two amplifiers: One amplifier is a carrier amplifier employing a chopper to modulate and demodulate a portion of the signal to be amplified; the second amplifier is a straight dc amplifier. The success of this circuit in reducing to a very low value the amount of drift appearing at the output depends upon the fact that the drift is a very low-frequency phenomenon. A block diagram of a chopper-stabilized amplifier is illustrated in Fig. 4.

A component of the output signal  $e_o$  is due to drift in the dc amplifier, and if it is fed back through the feedback resistor to the input of the chopper-modulated amplifier (it cannot be fed back to the dc amplifier because of the high-pass filter), the drift component will be amplified and returned to the dc amplifier. An analysis of the circuit shows that the input voltage  $e_s$  to the dc amplifier is altered by a factor equal and opposite to the equivalent drift voltage appearing at the input. The net result is that the drift can be reduced to a negligible value.

A signal appearing at the input terminals is amplified partly in the dc amplifier and partly in the chop-

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and 3. The channel spacing is also different, providing 32 channels, again using both senses of circular polarization. The transmitted power level allowed in region 2 was lowered from that in regions 1 and 3 to minimize possible interferences with other services and to take advantage of technology improvements in user receiver design.

Because of the differences between implementations by region, the complete equipment for signal reception may not be transportable across regional boundaries, although some components of the equipment can be used in all regions. Actual hardware differences are small, however, and do not represent a technology block. *See RADIO SPECTRUM ALLOCATIONS.*

**Development.** The *Communications Technology Satellite (CTS)*, a shared United States-Canadian spacecraft launched in 1976, included a high-power DBS experimental transmitter developed by Canada in addition to its equipment for other communications experiments. The Canadians followed this with other experiments on *ANIK-B*, launched in 1978.

In 1978, Japan launched *BSE 1*, a spacecraft totally committed to DBS experiments. It was beset with technical problems in its high-power transmission amplifiers, but was followed in 1984 by *BS 2*, which achieved operational status.

The West German *DBS TV-SAT 1* was launched in 1987 but failed to operate. Other countries with spacecraft projects with scheduled launches are France, Sweden, Ireland, and Great Britain.

**Technical problems.** Problems encountered in the implementation of a DBS system include rain attenuation, impact of high-power radio-frequency satellites, initial implementation cost, and establishment of a broad user base.

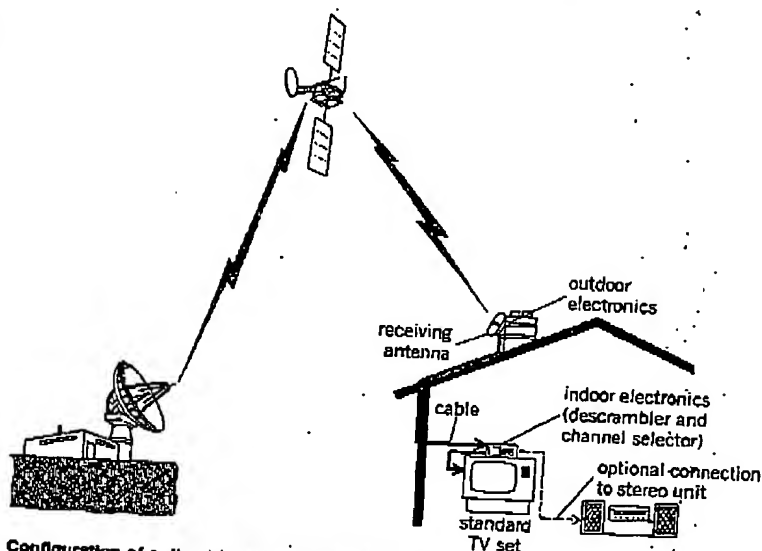
Rain attenuation is the degradation of received signal strength from the satellite when rain is present in the line of sight from the satellite to the homesat terminal. The signal strength may be reduced by a factor of 3 to 4 or more over clear air transmissions and may be severe enough in dense rain conditions to cause total loss of reception. The two solutions for this problem are more transmitter power in the spacecraft and a larger homesat terminal antenna.

The increased transmitter power in the spacecraft results in a reduction of the number of channels per spacecraft. This in turn causes a requirement for multiple spacecraft at a given orbit location. This problem is solved by management of precise orbit location and spacecraft to avoid possibility of collision and interference in the control signals to the spacecraft. Other technical problems are achieving the lifetime of the high-power satellite transmitter (10 years) and dissipating the thermal energy.

To implement the DBS system is much more expensive than that of a terrestrial distribution system per unit of coverage area. However, the DBS system is implemented over an entire time zone instantaneously and the total cost to implement becomes much lower. When the first DBS system is implemented, the system operator has the problem of installing transmitting hardware (the satellite) and a very small user population (homesat terminals) with a very small number of homesat terminals to the last problem of establishing a large enough size for the systems operator to make a profit.

**Considerations.** Of great importance in the implementation of a DBS system is the programming.

## Direct-coupled amplifier 327



Configuration of a direct broadcasting satellite system.

DBS systems, because of the possibility of vast numbers of viewers served, have the opportunity to provide special-interest broadcasting. The economics of the broadcasting of such specialty programming becomes profitable when, as in a DBS system with a large user base, a small percentage of the total viewing community can provide the necessary revenue. For the terrestrial-based systems, each station must provide broad-interest programming to maintain a large percentage of the viewer population to achieve profitability.

In addition to specialty broadcasting, the DBS system can provide both normal wide-area advertiser-supported and pay-for-view programming. *See COMMUNICATIONS SATELLITE; TELEVISION.*

**Bibliography.** R. F. Buntschuh, *First generation RCA direct broadcast satellites, IEEE J. Selected Areas Commun., SAC-3:126-134, 1985; Commercial Geosynchronous Communication Satellites*, Aviation Information Services Limited, Hounslow, England, 1988; *European Space Directory*, 3d ed., 1988; *Proceedings of the International Astronautical Federation*, Stockholm, October 1985; *Proceedings of the Symposium on Direct Broadcast Satellite Communications*, Washington, D.C., 1980.

## Direct-coupled amplifier

A device for amplifying signals with direct-current (dc) components. There are many different situations where it is necessary to amplify signals having a frequency spectrum which extends to zero frequency. Some typical examples are amplifiers in electronic differential analyzers (analog computers), certain types of feedback control systems, and some medical instruments such as the electrocardiograph. Amplifiers which have capacitor coupling between stages are not usable in these cases, because the gain at zero frequency is zero. Therefore, a special form of amplifier, called a dc (for direct-current) or direct-coupled amplifier, is necessary. These amplifiers will also

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